Impact of rainwater harvesting on the hydrology of Modder river basin

S.T. Tetsoane*, Y.E. Woyessa and E. Pretorius

School of Civil Engineering and Built Environment, Central University of Technology, Free State, Private Bag X 20539, Bloemfontein, 9300
* Corresponding author: Tel: +27-51 507 3089; E-mail: tetsoane@cut.ac.za

Abstract

The river basin is a geographical unit that defines an area where various users of the basin's water interact, and where most of them live. In a new paradigm shift related to integrated water resources management in the context of a river basin, attention is being drawn to consider the upstream 'off-site' influences on the various water use entities, as well as the downstream 'off-site' impacts arising from them. The Krugersdrift Dam, which is located west of the City of Bloemfontein, acts as a buffer for stabilising the water supply to the lower reaches of the Modder River. However, many of the rural small farmers rely on rainfed agriculture for crop production. In the past few years the Institute for Soil, Climate ad Water of the Agricultural Research Council has been developing rainwater harvesting techniques for small scale farmers for crop production. It has been reported that, with the use of this technique, the surface run-off was reduced to zero resulting in a significant increase in crop yield compared to conventional practices. The research questions arising from this scenario are: what will be the consequences of wider use of this practice on the hydrology of the catchment, and what will be the off-site impact of this practice on the downstream of the river basin if used on a wider scale? In trying to answer these questions a Water Resources Yield Model will be used to simulate the impact of the IRWH technique on the water balance of the Modder River. It is expected that the outcome of this research will shed some light on the impact, if any, of rainwater harvesting on the hydrology of the Modder river basin and on the downstream water users.

Keywords: *Rainwater harvesting, River basin, Hydrological model.*

1 Introduction

The river basin is a geographic unit that defines an area where various users of the basin's water interact, and where most of them live. A basin perspective helps include in the analysis the interactions among various types of water uses and users, and in the process, it helps in better understanding of the physical, environment, social and economic influences that impinge on the productivity of agricultural water management (Sunaryo, 2001). In a basin context, interrelated issues of quantity and quality of surface water and groundwater, and the extraction, use and disposal of water resources can be more comprehensively analysed. Participation of a larger number of stakeholders can be sought, and water resources planning can be more effectively carried out. The broader view through a river basin is able to capture dimensions that are not normally included in an irrigation system management approach, such as the causes (and not only the effects) of water scarcity, water quality, water-related disputes and inequitable water distribution and use (Bandaragoda, 2001).

An integrated approach to water resources management in a river basin would enhance both productivity and sustainability of natural resource use. Sustainability means that the concerns about resources use should transcend short-term on-site gains, and should necessarily focus on an environmentally sensitive use of resources including many possible off-site implications. For instance, in many irrigation systems, the act of water use is limited to achieving system objectives, such as obtaining highest crop yields, and is rarely concerned with downstream drainage problems or pollution caused by fertilizers and other chemical inputs. The off-site influences on a water use system, as well as the off-site impacts arising from a water use system, can both be systematically studied to identify the factors that affect the performance of the water use system.

2 Methodology

2.1 Description of the Upper Orange Water Management Area

The Upper Orange water management area (WMA) lies to the centre of South Africa and extends over the southern Free State and parts of the Eastern and Northern Cape provinces. The water management area also borders on Lesotho to the east,

where the Orange River originates as the Senqu River (see Figure 1). Draining the Highlands of Lesotho, the Senqu River contributes close to 60% of the surface water associated with the Upper Orange water management area, at the point where it enters South Africa to become the Orange River. The climate varies considerably over the region, and rainfall ranges from over 1000 mm per year in the foothills of the mountains, to as little as 200 mm per year in the west. Vegetation is mainly grass land. Extensive sheep and cattle farming are characteristic throughout the water management area. Some dry land cultivation occurs where the rainfall and soils are favourable, with sizeable areas under irrigation below the main storage dams. Bloemfontein, as an administrative and commercial centre, is the only large urban development in the water management area.

Water resource management in the water management area mainly revolves around the Orange River. Two of the highest dams in Africa have been constructed in the Orange (Senqu) catchment in Lesotho for transfer of water to the Upper Vaal water management area. The Gariep and Vanderkloof Dams in the water management area, where the two largest conventional hydropower installations in the country are located, also command the two largest storage reservoirs in South Africa. Another major inter-water management area transfer of water is from Gariep Dam, via 80 km long Orange-Fish Tunnel, to the Fish to Tsitsikamma water management area, while a significant portion of the yield is also released along the river for use in the Lower Orange water management area as well as by Namibia. In total, close to 70% of the yield released in the Upper Orange water management area and Lesotho together, is used in other water management area. Significant quantities of groundwater are used in parts of the water management area. The Modder and Riet tributaries have been fully developed. Demographic projections show a small decline in rural population, which is balanced by growth in the Bloemfontein area, resulting in little change in the total population of the water management area within the period of projection (DWAF, 2002).

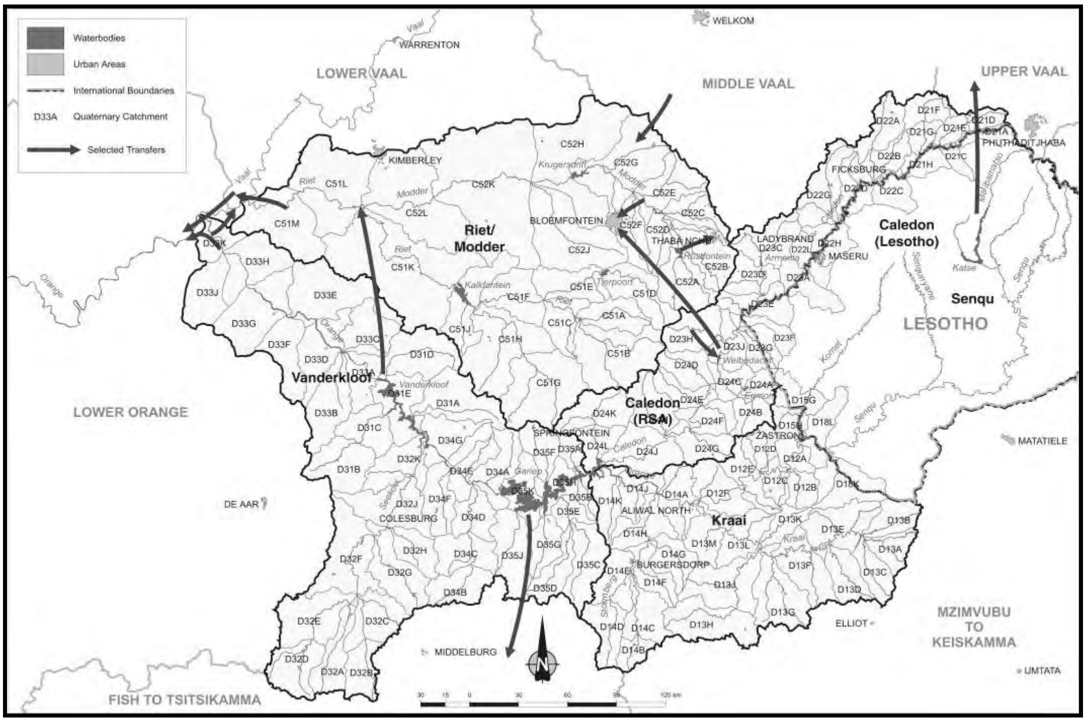

Figure 1. Upper Orange Water Management Area (from DWAF, 2002).

2.2 Description of the Modder River basin area

The whole Modder River is a larger basin with a total of 1.73 million hectares. It is divided into three sub-basins, named as the Upper Modder, the Middle Modder and the Lower Modder. It is located within the Orange Water Management Area to the east of the city of Bloemfontein (central South Africa). The irrigated agriculture in the basin draws water mainly by pumping out of river pools and weirs. However, most of the rural developing farmers rely on rainfed agriculture for crop production. The water supply to the middle and lower reaches of the Modder River is stabilised by the Rustfontein and Mockes Dams in the east and Krugersdrift Dam in the west of the city of Bloemfontein.

Four sub-catchments, located in the Upper and Middle Modder River basin have been selected for this study (Figure 2). These are C52A, C52B, C52C and C52D. The areas (in ha) of each of these sub-catchments are: C52A = 93,671, C52B = 94,935, C52C = 47,129 and C52D = 60,031, and with a total area of 295,766 ha.

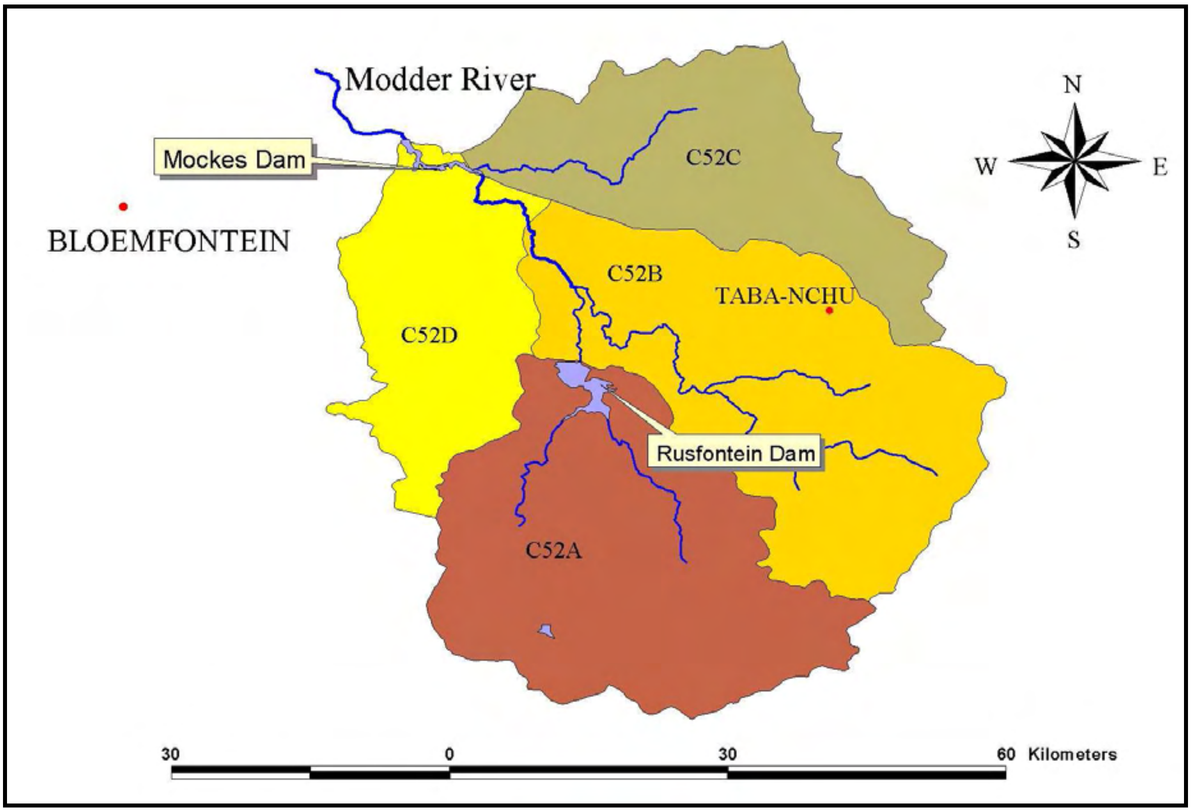

Figure 2. Map of the study site showing of the location of Rustfontein and Mockes Dams.

2.3 Data type and analysis

Long term data on the hydrology of the catchment, such as precipitation and runoff were obtained from a database of surface water resources of South Africa (Midgley et al., 1994). With the identification of the suitable area of land for IRWH in the study area, based on soil and topographical information, the mean annual runoff was estimated for the whole catchment and the possible impact of IRWH technique on runoff generation was quantified. For the simulation of the impact of the IRWH technique on the water balance of the catchment a model called Water Resources Yield Model (WRYM) has been identified and will be employed at a later stage. The WRYM is a network model which uses a sophisticated network solver to analyse complex water resource systems under various operating scenarios. The strength of the model lies in the ability to change the operating rules via the external data files and no changes to the actual program source code are required (Rossouw, 2005).

3 Results and Discussion

A reduction in runoff will result from practices that successfully increase the infiltration capacity of the soil, increase the contact time, and/or reduce surface sealing. The evaporation from the soil surface will be reduced in using this practice by covering the surface with the mulch. The infield rainwater harvesting technique, whereby runoff is captured in a micro basin, is found to reduce runoff from the field to zero by converting to stored soil water, and consequently to increased yields, compared with conventional tillage. The effect of the IRWH technique on retention of runoff being obvious, it is only suitable on type of soils which has low infiltration rate whereby the water retained will be used by the crops and where slope of topography is between 0 % - 4 %.

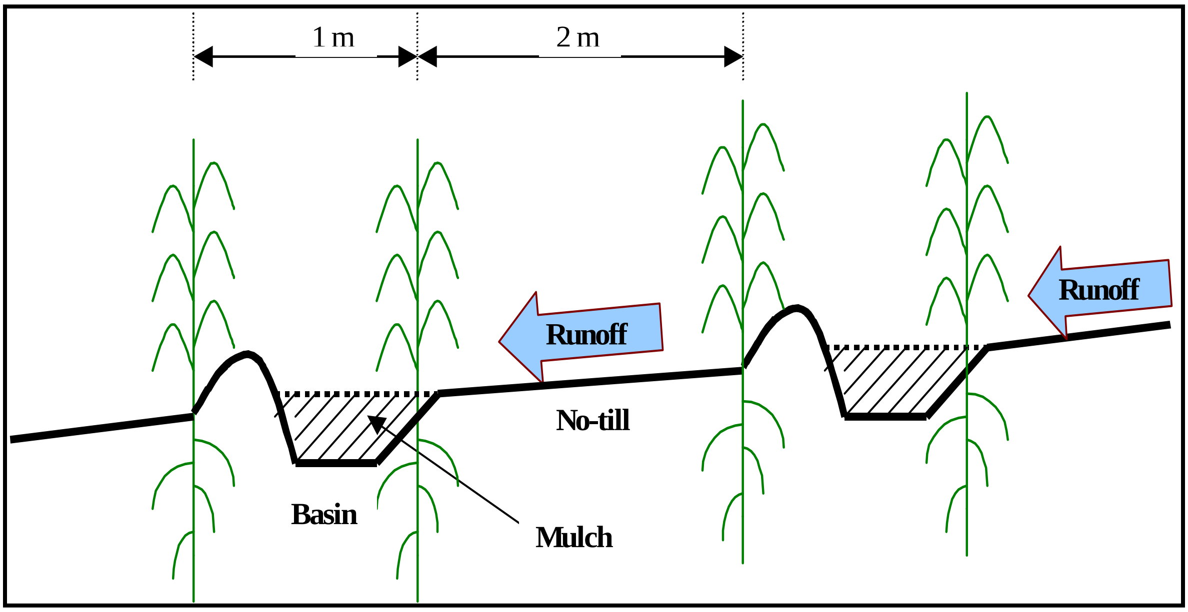

Figure 3. Diagrammatic representation of the IRWH technique (from Woyessa et al., 2005).

The runoff generated from C52A, one of the sub-catchments in the study area, is captured by the Rustfontein Dam. The remaining sub-catchments, such as C52B, C52C and C52D drain into the Mockes Dam. Gauging stations placed at the vicinity of the two Dams measure the incoming runoff water into the Dams. This data is available for the Rustfontein Dam for 36 years giving the mean annual total runoff coming into Rustfotein Dam from a catchment area of 93,670 ha (i.e., area of C52A) as 34.73 million cubic meters (Midgley et al., 1994). The mean annual precipitation for the study area is 550 mm. Based on these values the mean runoff coefficient was calculated to be 6.6%, which is similar to the values obtained at experimental sites on conventional plots (total soil tillage) at Glen experimental station (Hensley et al., 2000). Rustfontein Dam has a full supply capacity (FSC) of 71.2 million cubic meters of water. The level of water, as of the 20th of July 2005 (at the time of write up of this paper), was at 58.8% of the FSC (Figure 4). This is equivalent to the mean annual inflow of runoff into the Dam (i.e. 33.5 million cubic meters).

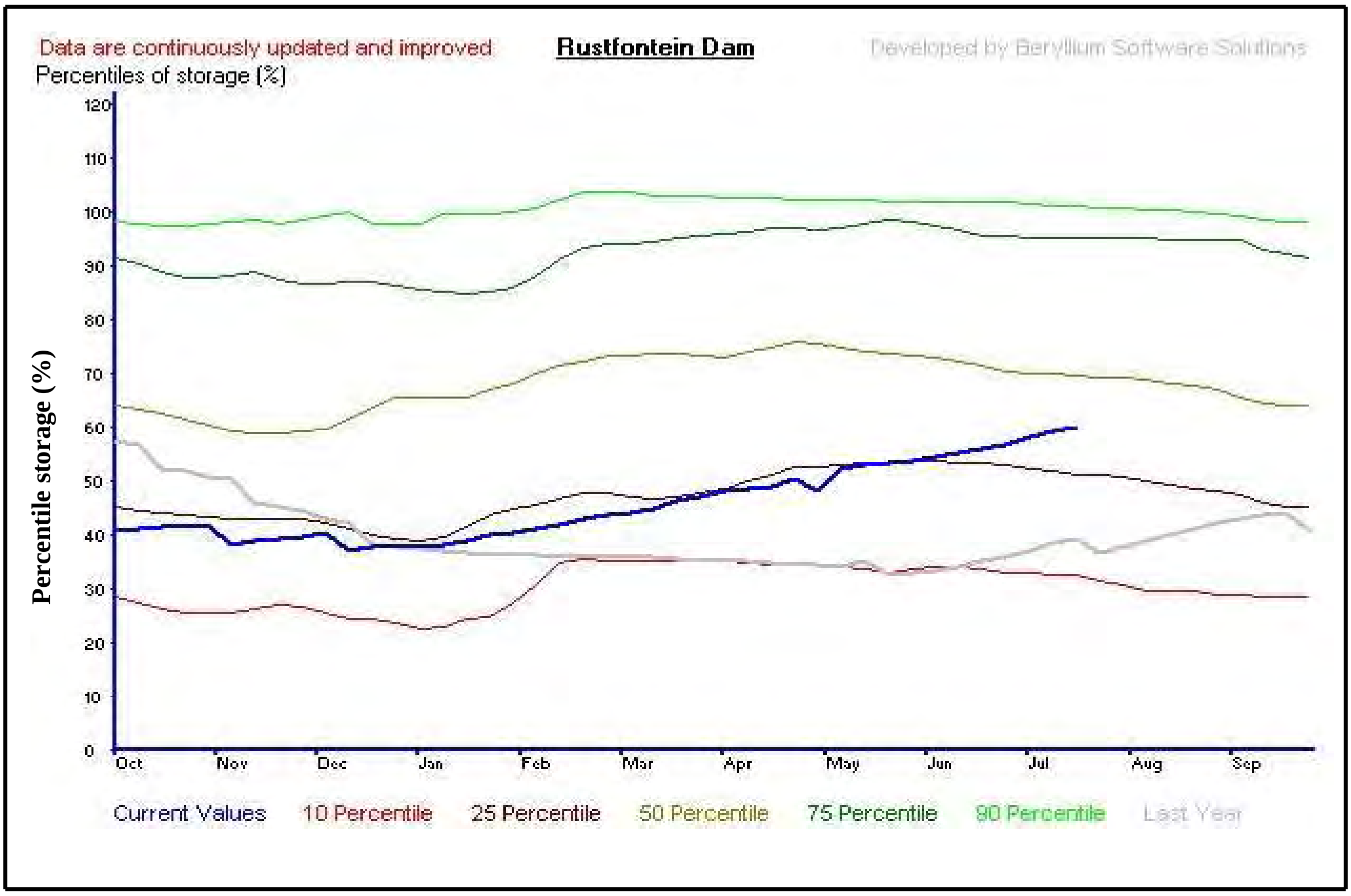

Figure 4. Water storage level in Rustfontein Dam on 20/07/2005 and percentile storage (Source: DWAF-online; accessed on 20/07/2005). Note: On the 20th of July 2005, the level of water in the dam shows 58.8% of the full supply capacity, or 41.9 million cubic meters. The full supply capacity is 71.2 million cubic meters. The current water level in the dam lies above the level for last year of the same period.

Each of these areas will affect runoff generation and its subsequent flow into the Dams. The magnitude of the effect of IRWH on the inflow of runoff into the Dams depends on the total area suitable for this technique. Details regarding runoff generation from the catchment and the possible effect of IRWH on the annual inflow into the Dams are given in Table 1.

Table 1 shows possible scenarios of what may be expected if all the suitable land in the catchment is put under cultivation using the IRWH technique. The area of land suitable for the IRWH technique is estimated to be 27% of the total area of the catchment in the study area (Woyessa et al., 2005). If all runoff from this portion of the catchment is retained for on-site use for crop production, it is estimated that it will reduce the mean annual runoff from 107 to 78 million cubic meters, i.e. a reduction of 29 million cubic meters. It should be noted that, in this part of the country, mean annual evaporation (Class A pan) is 2198 mm (Botha et al., 2003) which can cause a tremendous amount of water loss from Dams, rivers and other storage reservoirs. For instance, with the storage surface area of Rustfontein Dam which is 1158.5 ha, it is estimated that 25 million cubic meters of water is lost annually through evaporation. In this context, the on-site use of rainwater at upstream level for food production may contribute to the reduction of non-productive water loss due to evaporation.

Table 1: Estimated runoff and possible impact of the IRWH technique on the inflow of runoff into the Dams (from Woyessa et al., 2005)

Parameters	Values
Mean annual precipitation (mm)	550
Mean annual runoff draining into Rustfontein Dam (m^3)	34 x 10^6
Mean annual runoff draining into Mockes Dam (m^3)	73.4 x 10^6
Area (ha) of catchment draining into Rustfontein Dam	93 671
Area (ha) of catchment draining into Mockes Dam	202 095
Runoff coefficient (%)	6.6
Total area of the catchment (ha)	295 700
Total suitable area for the IRWH (ha)	80,667
Suitable area as % of the total area of the catchment	27
Mean annual runoff from the total area (m^3)	107 x 10^6
Mean annual runoff retained in the IRWH area (m^3)	29 x 10^6

However, the assumption of the scenario of all the suitable land for IRWH being put under cultivation using the technique should be seen in relation to the following factors.

Firstly, the current form of the IRWH technique has been designed for implementation using hand labour, and therefore only suitable for the relatively small areas expected to be developed initially by communal farmers living in the catchment area. The estimated area of suitable land for the IRWH inhabited by communal farmers is 15 000 ha. At present the IRWH technique is employed almost exclusively by large numbers of the communal farmers in their backyard gardens. The rate of expansion into the 15 000 ha of communal cropland is expected to be determined by the extent and rate at which certain constraints can be overcome.

Secondly, research is currently being planned by the ARC-ISCW to mechanize the IRWH technique and make it suitable for commercial production. If this proves to be successful, expansion would probably be accelerated. The technique may then even be employed by the commercial farmers on the remaining 65 667 ha of suitable land for IRWH in the catchment.

4 Conclusions

The preliminary estimation of the impact of the IRWH technique showed that there will be runoff reduction by approximately 27% of the total annual runoff if all the suitable land is put under cultivation using the technique. However, the impact of this technique on water resource yield need to be further investigated using appropriate models, which will be the remaining task of this research project. In order to achieve this, there are various models that can be used to simulate the whole water balance of a catchment. In this study a model called Water Resources Yield Model has been identified for use. The Water Resources Yield Model is a network model which uses a sophisticated network solver to analyse complex water resource systems under various operating scenarios. The strength of the model lies in the ability to change the operating rules via the external data files and no changes to the actual program source code are required. The WRYM analyses systems at constant development levels, i.e. the system and the system demands remain constant throughout the full simulation period. The model calculates the water balance throughout the system on a monthly basis.

It will be interesting to see how the water balance will be affected if the IRWH technique is added to the yield analysis model of the catchment. It is expected that, with the use of the model, this research will try to shed some light on two important questions: (1) what will be the consequences of wider use of this practice on the river water balance and yield; and (2) what will be the off-site impact of this practice on the downstream of the river basin if used on a wider scale?

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